REFORMS OF YEREVAN TRANSPORT SYSTEM IN THE CONTEXT OF LOW-CARBON DEVELOPMENT POLICY

REPORT

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Yerevan, 2020

The objective of the report is to calculate the volume of emissions from the transport sector of Yerevan, and to submit medium-term and long-term policies aimed at reducing emissions from the transport sector in Yerevan.

This publication has been prepared with the financial support of the European Union. The EU-UNDP "EU for Climate" regional program is held liable for the content, and the views and opinions expressed in this document do not necessarily reflect the views of the European Union.

CONTENTS

I. INTRODUCTION

This report has been prepared within the framework of the EU-UNDP "EU for Climate" regional program. It describes the key problems of reducing emissions from the transport in Yerevan in the context of medium-term and long-term term policies of climate change mitigation, taking into account international experience, the EU vision and the provisions of the EU-Armenia Comprehensive and Enhanced Partnership Agreement (CEPA).

Based on the data available in the existing databases of vehicle registration in Armenia, a study has been conducted to describe the current situation in the transport sector, the development trends, directions and opportunities to impact and manage them, taking into account the types of vehicles, targeted use, engine type (according to fuel used).

As a result of the data study, observations have been made, recommendations have been submitted, different approaches to the development of the transport sector have been elaborated, taking into consideration the reduction of emissions from the sector, and the development of alternative energy vehicles operation in Yerevan.

Based on the best international experience in the field of transport management and assessing the potential and opportunities for reducing emissions from the transport in Yerevan, the main strategies and tools to promote the reduction of emissions in Yerevan, prospects for transport development, medium-term and long-term policies have been submitted.

II. SITUATION DESCRIPTION AND KEY INFORMATION

1. Global and regional context of climate change resilience

By ratifying the Paris Agreement on Climate Change, the Republic of Armenia undertakes international commitments through the document of Nationally Determined Commitments. Reduction / limitation of greenhouse gas (GHG) emissions from the transport sector is highlighted by this document.

In 2018 the **Comprehensive and Enhanced Partnership Agreement (CEPA)** was signed between the EU and the Republic of Armenia; for its implementation a roadmap for joint actions of the agreement has been developed and approved. The roadmap for the CEPA includes a special section on air quality management, for the realization of which the policy implemented in the transport sector is of great importance.

Problem statement	Action	Expected result	Bench-mark	Time-frame
Need for less atmospheric air pollution.	Establish daily average permissible concentrations of hazardous substances polluting atmospheric air and monitoring measures according to the EU standards.	Clarification of permissible amounts of harmful emissions and the list of these substances, reduction of harmful emissions, less air pollution. As a result, improvement of atmospheric air quality and reduction of diseases caused by polluted air.	Adoption of relevant standards.	six months
Need for less atmospheric air pollution.	Define by legislation the procedure for granting the right for the emission of hazardous substances polluting atmospheric air and bring it into line with EU standards.	Clarification of production units and specific permissible cases, reduction of units producing new harmful emissions, stricter ecological liability for new production units, less atmospheric air pollution. As a result, improvement of atmospheric air quality and reduction of diseases caused by polluted air.	Adoption of relevant standards.	one year

In 2017, Yerevan Municipality, with the support of the European Bank for Reconstruction and Development, elaborated the **Green City Action Plan (GCAP) for Yerevan.** The methodology of the "Green City" action plan highlights the environmental challenges of the community, assessing the condition of the city's air, water resources, soil, biodiversity and ecosystems, the negative factors affecting them and the existing legislative solutions based on internationally approved standards.

The plan includes the following sections: state of environmental assets (air, soil, water, biodiversity and green areas), environmental pressures, transport, energy supply, energy efficiency in buildings and outdoor lighting, industries, waste management, land use. The plan also includes provisions on management and monitoring.

GCAP aims at sustainable community development, community settlements improvement and landscaping, waste collection and public utilities improvement, public transportation reform, road infrastructure optimization, disaster risk reduction and resilience growth, environment and public health protection.

Marrakech Partnership for Global Climate Action (Marrakech MPGCA)[1] is the support of non-governmental organizations for the implementation of the Paris Agreement in the context of the 2030 Agenda for Sustainable Development. The above-mentioned partnership includes the following areas:

1. General public transportation,
2. Freight and logistics,
3. Fuel consumption efficiency and electric motors application,
4. Bicycles and walking,
5. Aviation,
6. Transport technologies,
7. Road transport.

All of the previously mentioned measures pursue one objective: to mitigate the rate of environmental pollution in each area by setting specific regulatory standards.

2. Brief overview of Yerevan

Yerevan as an administrative center

Yerevan is the capital city of the Republic of Armenia. At present Yerevan is the largest economic, scientific and cultural center of Armenia, the most important transport and transit hub for regional transportation. In total, 42.1% of Armenia's industry, 53.9% of construction, 82.6% of retail trade, 85.5% of services, 77.6% of residential housing construction and 33.2% of hotel business is concentrated in Yerevan.

The offices of all the three branches of the government: the legislature, the executive and the judiciary are located in Yerevan. For effective local government and regional administration, Yerevan is divided into the following 12 administrative districts: Ajapnyak, Avan, Arabkir, Davtashen, Erebuni, Kentron, Malatia-Sebastia, Nor Nork, Nork-Marash, Nubarashen, Shengavit, Kanaker-Zeytun.

[1] unfccc.int/climate-action/marrakech-partnership-for-global-climate-action

Geographic location

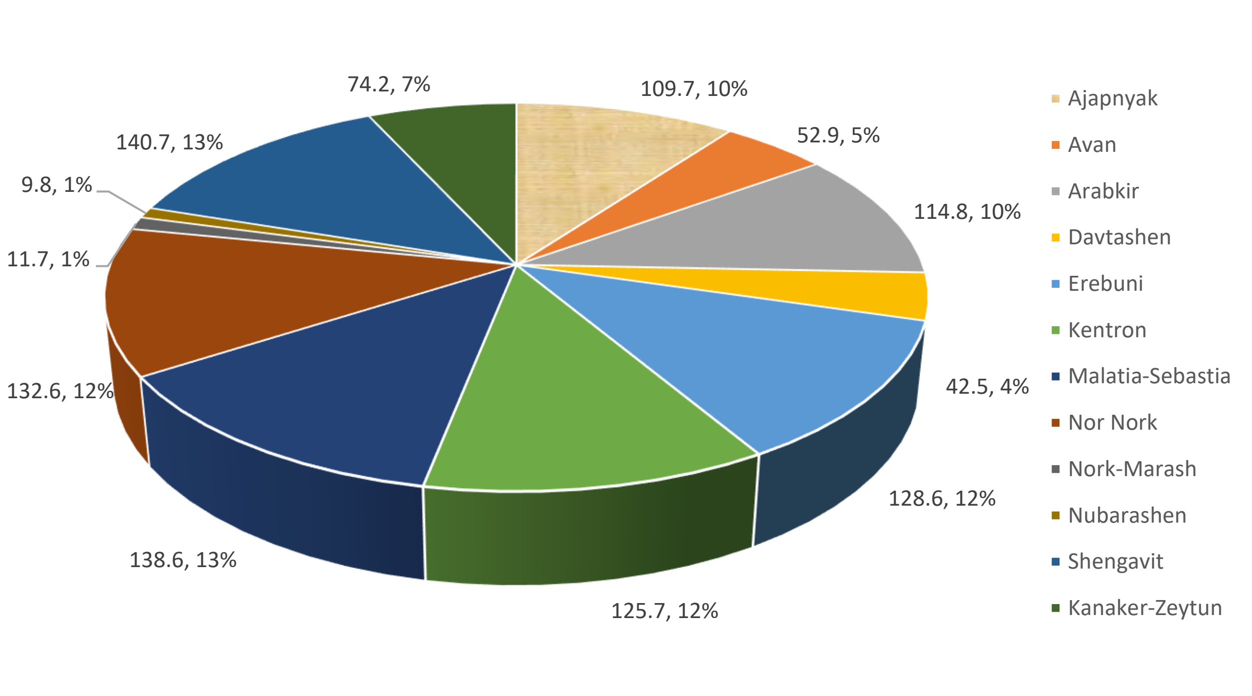
Yerevan (400 N, 440 E) is located in the north-eastern part of Ararat Valley, on both banks of the Hrazdan River, at an altitude ranging between 850-1300 m above sea level. Geological formation is that of young volcanic rocks and sedimentary basements, with seismicity ranging between M7-M8. The total area of the city is 223 km^2, stretching 19.7 km from north to south and 19.1 km from east to west. Yerevan, as the rest of the country, is located in GMT+4 time zone. The city has the form of a circus with the centre in the lower part of it and the residential districts in the upper parts. The lowest points are in the southern districts of Shengavit and Malatia-Sebastia. Avan and Nor Nork administrative districts have the highest location. The central square of the city, the Republic Square, is located at an altitude of 1000 m above sea level.

Figure 1. Administrative map of Yerevan

Urban population

As of January 1, 2019 the urban population amounted to 1081.8 thousand. The distribution of Yerevan population by administrative districts is shown in Figure 2.

Figure 2. Distribution of Yerevan population by administrative districts (thousand people)



3. Transportation system and vehicles of Yerevan

Primary streets and roads, that constitute the base of the road and street network of Yerevan, provide the major traffic flow. The main transport communications are provided through primary streets that interconnect the adjacent suburban residential areas and through radial primary roads that start from the central part of the city. Due to unequal distribution of public and private transport operation in the city, the main traffic load falls on the central part of the capital.

The current operating route network of public transportation in Yerevan is serviced by buses, trolleybuses, minibuses and the underground.

Table 1. Indicators of public transportation operating in Yerevan

Type of vehicle	Number of vehicles (PCs)
Bus	522
Minibus	1400
Trolleybus	45
Total	1967

“Yerevan electric transport” CJSC has 79 trolleybuses (1 for technical aid) on its balance, including 9 “Renault”, 34 “Škoda” and 35 “LIAZ” models. The company operates 5 trolleybus routes; and, on average, 46-48 units of vehicles are used daily to service the route.

The Yerevan underground has 10 stations; the length of the railway measures 12.1 km; 45 wagons are put in operation. On weekdays 26 wagons (13 rolling stocks) are operated, while at weekends 24 wagons (12 rolling stocks) are operated.

The bus fleet consists exclusively of medium-sized buses with limited traffic capacity of 18-22 seats with limited space for standing passengers. The current fleet is equipped with the following vehicles of different models:

- “HIGER” 249 PCs (195 in service), 6 years old,
- “BOGDAN” 142 PCs, 77%, 10 years old and more,
- “HYUNDAI” 143 PCs, 7 years old,
- “PAZ” 27 PCs, 12 years old,
- “JIJIANG” 15 PCs, 4 years old.

These transportation means use diesel as motor fuel, except for a part of the imported "HIGER" buses, which have been converted / re-equipped for operation with compressed natural gas (CNG). Currently, 40 bus routes are in operation, which are serviced by 522 buses.

The main part of public transport vehicles in Yerevan consists of minibuses serviced by private operators. This part of the network provides about 53% of passenger traffic. The minibuses are of "GAZelle” model that are manufactured in the Russian Federation. There are more than 1,400 minibuses registered, but the number of vehicles in daily operation is likely to be smaller. All minibuses have been converted for operation with compressed natural gas. About 75% of these vehicles are over 10 years old. In conditions of such intensive operation, the useful life of these vehicles is less than 5 years. Expert observations indicate that most of the fleet is in an unsatisfactory state, which may lead to security problems, as well as in 2020 the question of decommissioning them will arise. Currently 66 minibus routes are serviced by private operators using such vehicles.

Data collection has been carried out using the information available in the vehicle register of the Traffic Police of the Republic of Armenia. According to the mentioned register, the vehicles are classified into the following types:

1. Passenger cars,
2. Trucks,
3. Buses,
4. Special vehicles,
5. Other.

Figure 3. Vehicles registered in the RA by type, 2020

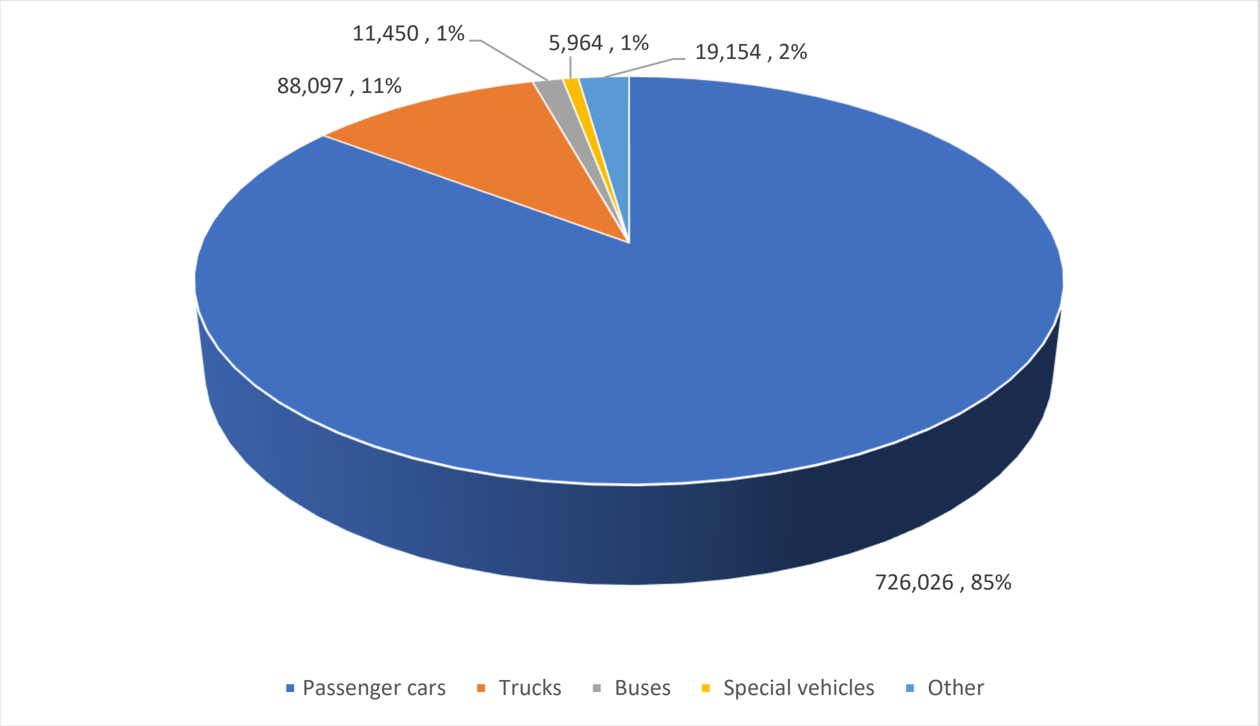


Table 2. Vehicles registered in the RA as of 2020

Vehicle type	**Number of vehicles (PCs)**
Passenger cars	726,026
Trucks	88,097
Buses	11,450
Special vehicles	5,964
Other	19,154
Total	850,691

Information about existing vehicles registered in the provinces of the Republic of Armenia as of 2020 is shown in Figure 4.

Figure 4. Number of vehicles registered in the RA by provinces, 2020

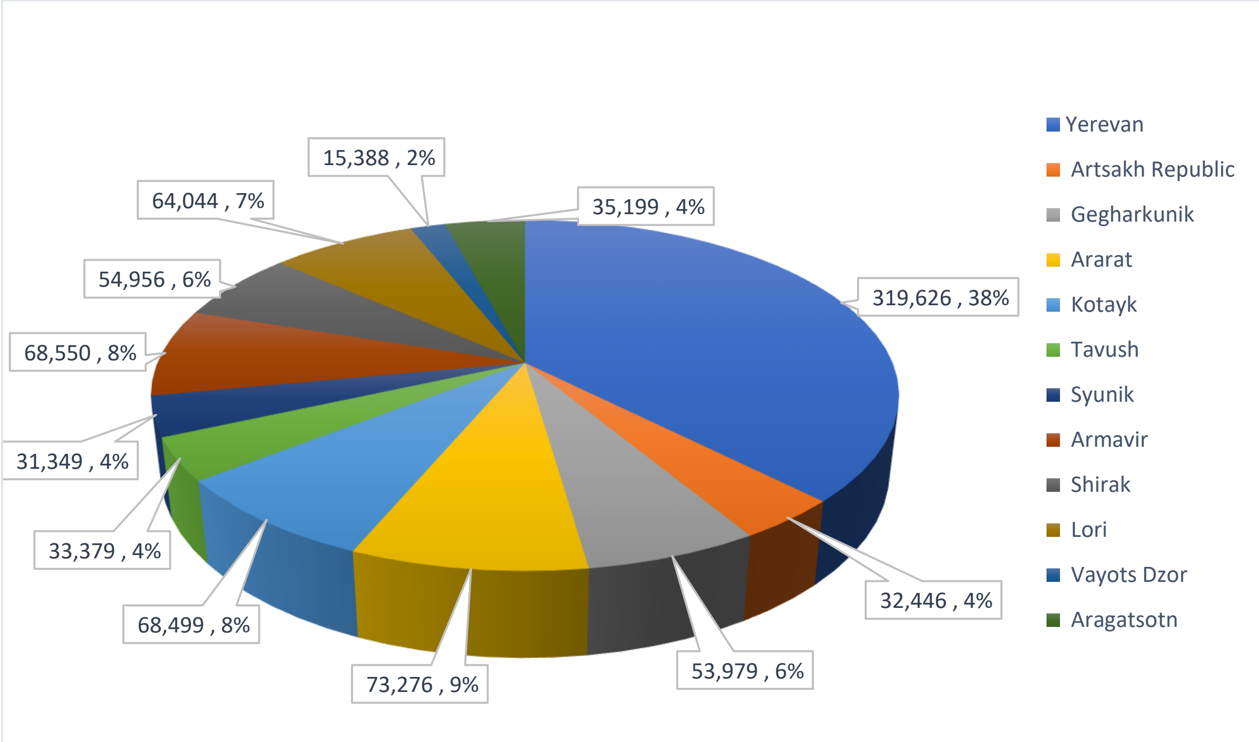
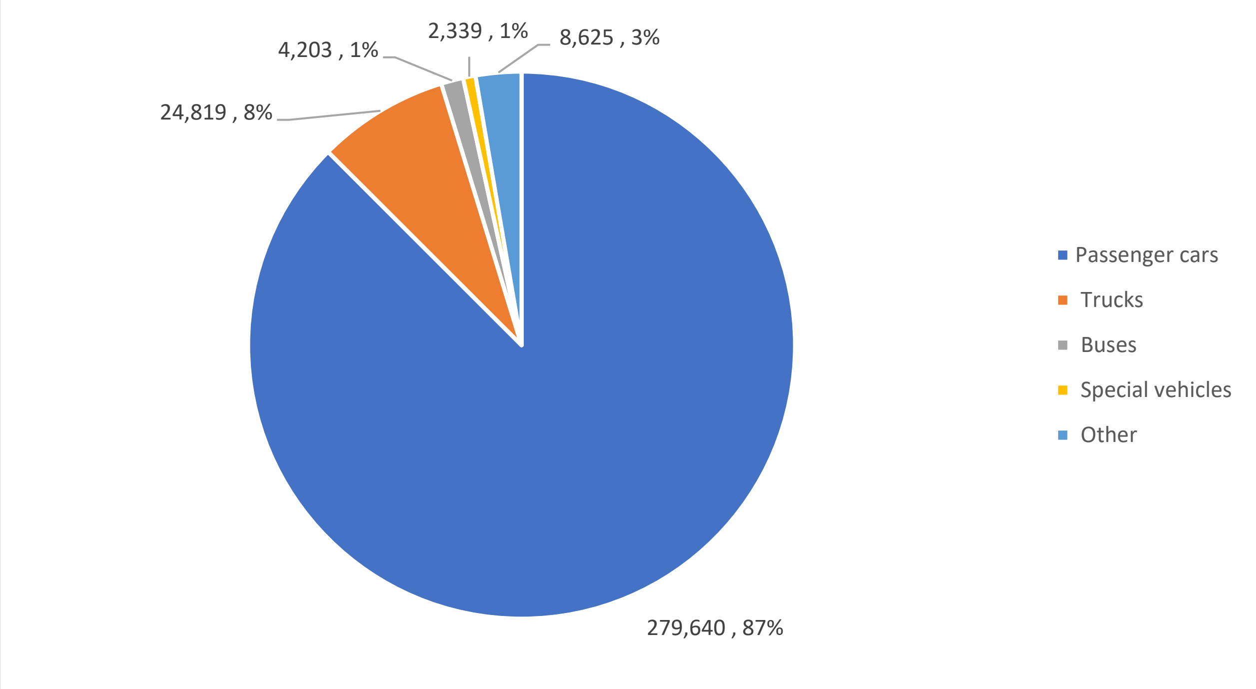


Table 3. Vehicles registered in the provinces of the Republic of Armenia as of 2020

Province	Number of vehicles (PCs)
Yerevan	319,626
Artsakh Republic	32,446
Gegharkunik	53,979
Ararat	73,276
Kotayk	68,499
Tavush	33,379
Syunik	31,349
Armavir	68,550
Shirak	54,956
Lori	64,044
Vayots Dzor	15,388
Aragatsotn	35,199
Total	850,691

As can be seen from the above figures, 850,691 vehicles are registered in the RA, 38% of which (or 319,626 PCs) falls to the share of Yerevan: 85% of all the vehicles registered in the RA are passenger cars. The distribution of vehicles by type in Yerevan is as follows:

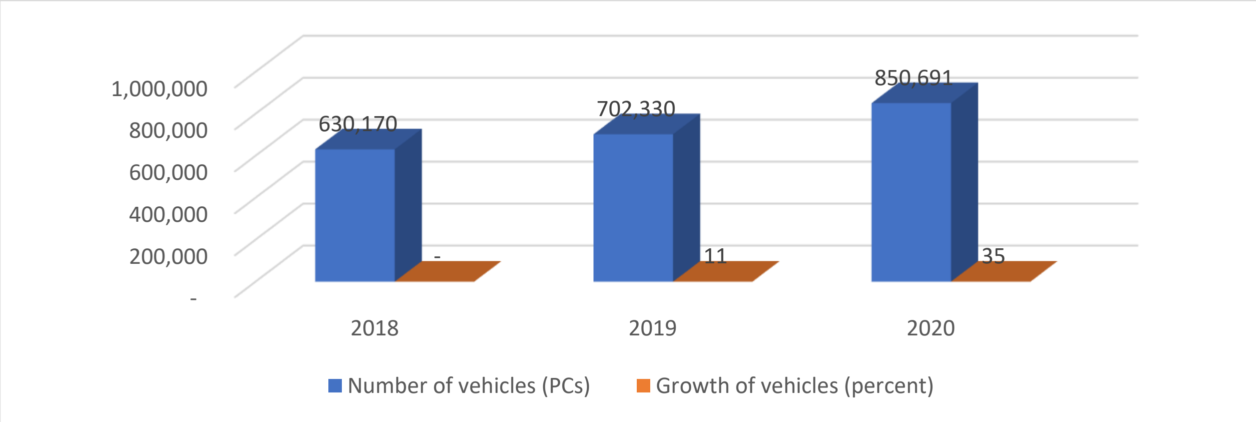
Figure 5. Vehicles registered in Yerevan, 2020



87% of all the vehicles registered in Yerevan falls to the share of passenger cars (Figure 5).

The vehicles recorded in the RA Traffic Police register also have significant growth tendencies (Figure 6).

Figure 6. Vehicles recorded in the RA Traffic Police register, 2018-2020



In percentage terms, the growth of vehicles in 2019 amounted to 11% compared to the previous year, and in 2020 the growth made up 34% compared to the previous year. The mentioned growth was mainly conditioned by 2020 transition to a single tax on the import of EEU vehicles, which obviously cannot increase at the same rate after 2020.

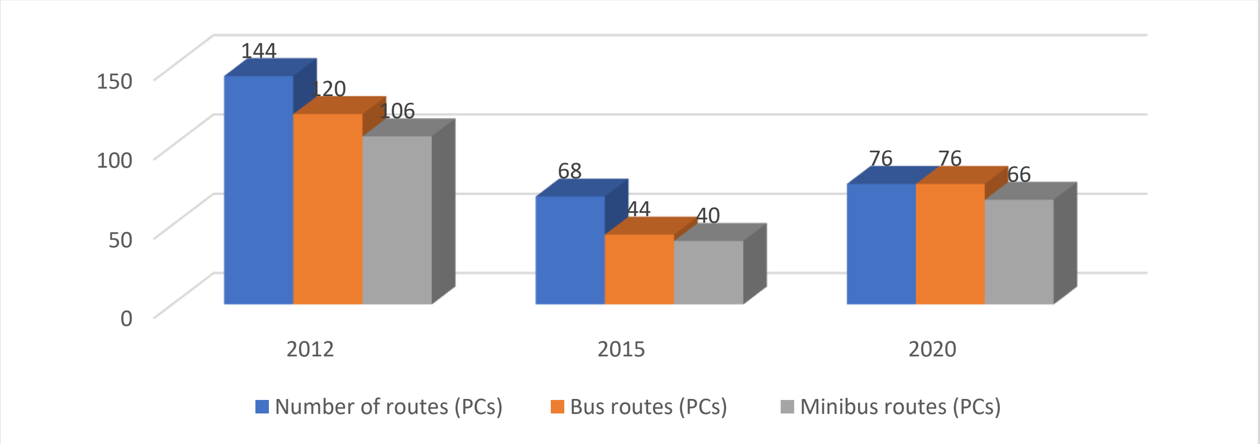
III. IDENTIFICATION OF PUBLIC TRANSPORTATION PROBLEMS IN YEREVAN

Reforms of Yerevan public transportation are an urgent process for the city authorities. The reform process started due to problems in the current public transportation network. The main problems are caused by the inefficient structure of the existing route network, as a result of which there are a number of routes that mostly overlap other routes and are serviced by various private operators.

Because the passenger traffic of public transportation in Yerevan is stable, the profitability of private operators is reduced, as in some parts of the city, due to overlapping routes, passengers fall to the share of some operators, and due to the natural wear and tear of the fleet, the cost of operating and maintaining the fleet also increases. As a consequence, private operators do not wish to make new capital investments due to declining profitability and annually refuse to service some unprofitable routes.

In 2013, the city authorities conducted an analysis and the unprofitability of public transportation was substantiated by financial calculations. The fact of unprofitability of public transportation in Yerevan is also proven by the statistics of closing routes (Figure 7).

Figure 7. Dynamics of public transportation routes in Yerevan, 2012, 2015 and 2020



Since 2012, the current public transportation network of Yerevan has been reduced by 28 bus routes and 10 minibus routes. These reductions in the current public transportation network cause a decrease in transport coverage: as a result, some parts of Yerevan are not serviced by public transportation.

There were two possible solutions to regulate the problem: increase the fare or modify the route network and design a financially efficient new one.

The reform of Yerevan transport sector, being a necessary and unavoidable process, also presupposes a political process component for the city authorities.

The need for reforms was also confirmed by the results of surveys, which provided information about the problems related to public transportation in Yerevan, according to the priorities.

The figures below demonstrate the dissatisfaction index of the population, recorded in the course of a social survey, by type of public transportation.

Figure 8. Dissatisfaction index of Yerevan public transportation: minibuses

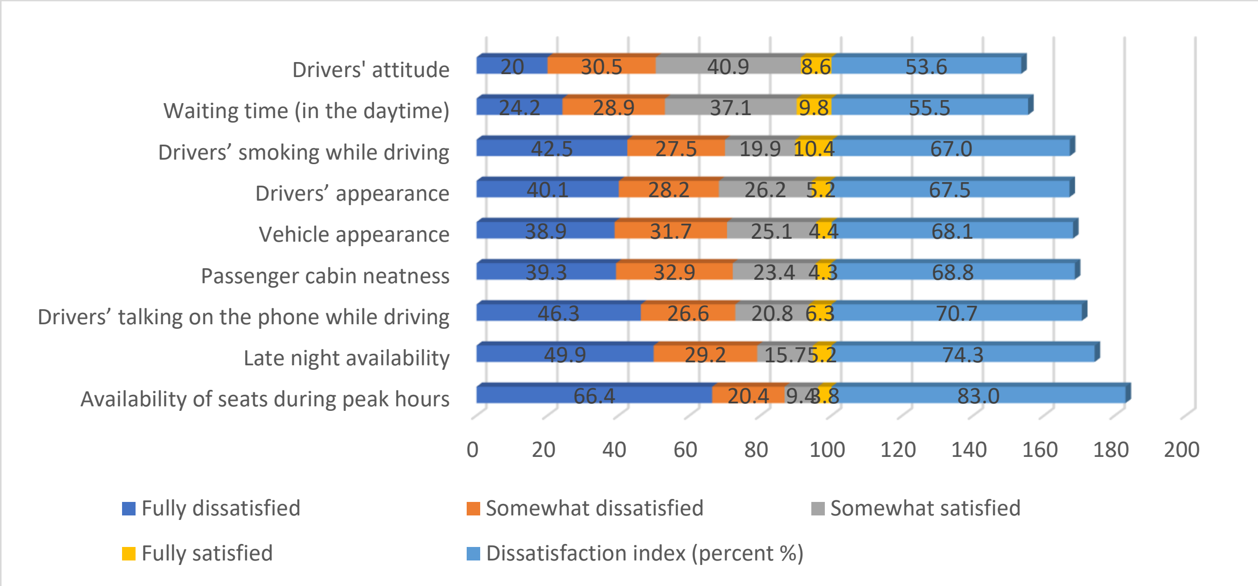


Figure 9. Dissatisfaction index of Yerevan public transportation: trolleybuses

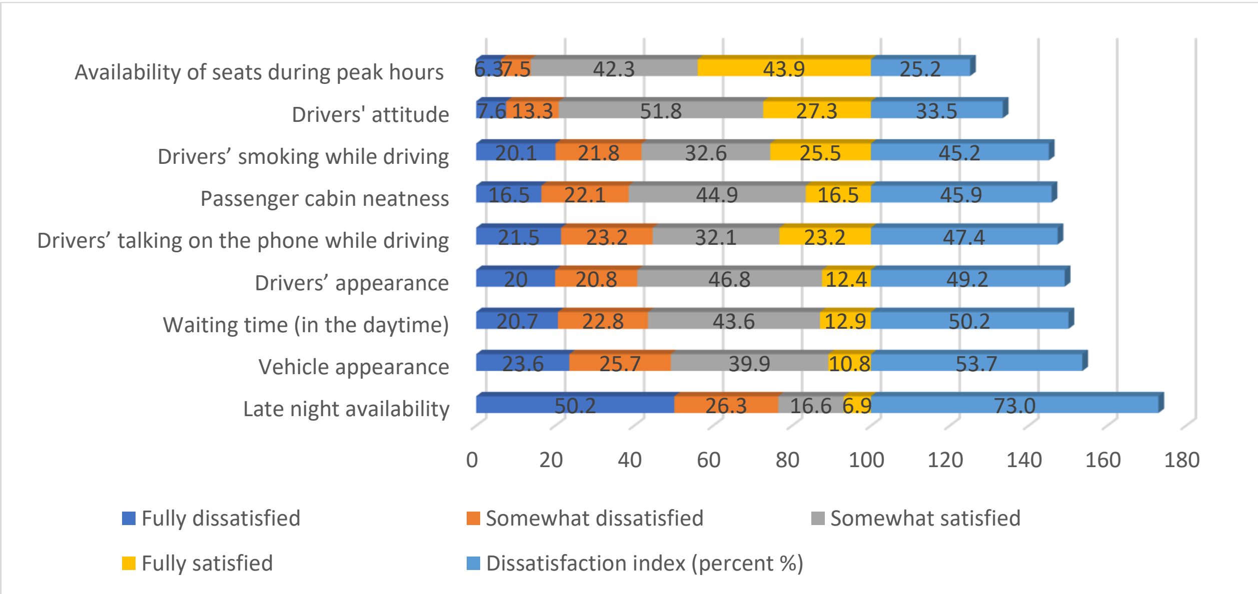


Figure 10. Dissatisfaction index of Yerevan public transportation: buses

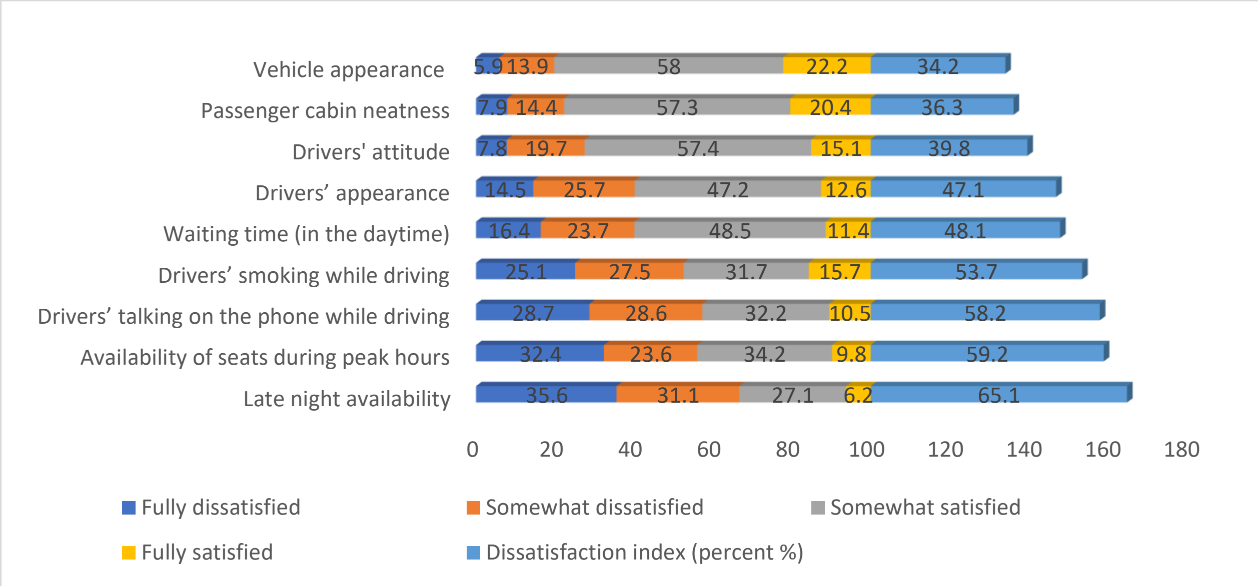
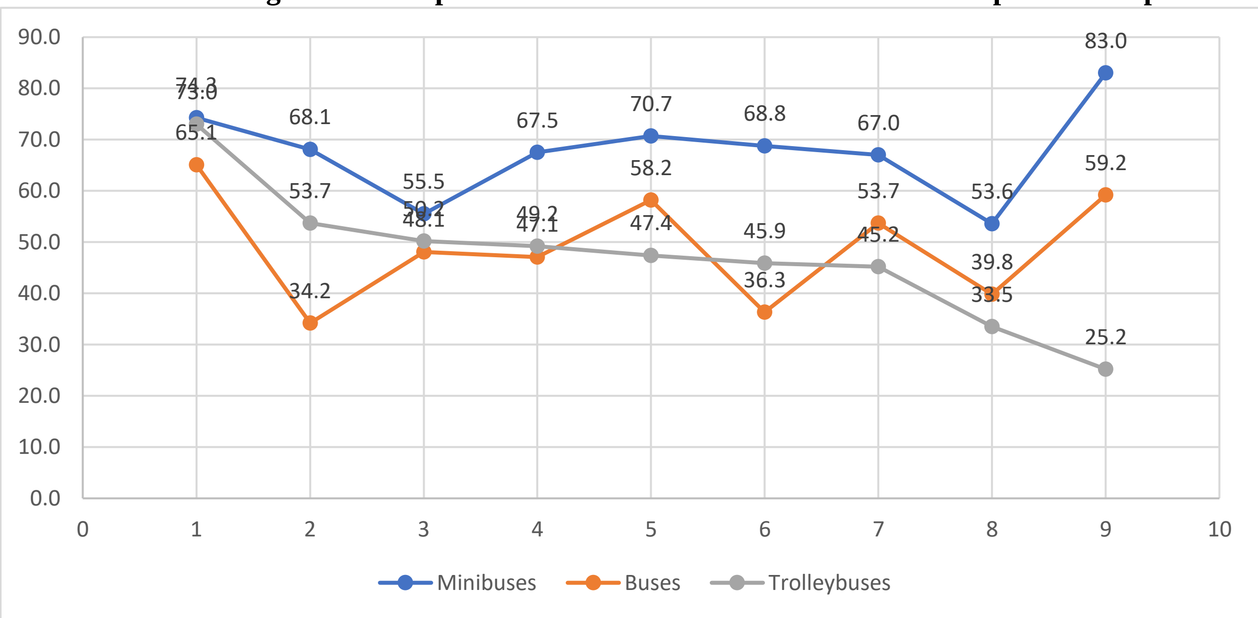


Figure 11. Comparison of dissatisfaction indices of Yerevan public transportation



Discussions on the implementation of transport reforms, as well as social surveys carried out in 2017, highlight that network operation has a number of objective problems, even in the event of a new vehicle fleet:

1. Poor maintenance of public transport, which is manifested by the lack of free seats in vehicles, transport availability in the late hours, neatness, etc.
2. Poorly designed network of public transportation: as a consequence, instead of complementing one another, the route lines are in constant competition, which leads to an increase in the total mileage of public transport, thus resulting in emissions growth.
3. Lack of stops: as a result stops are made in unappropriated places (anywhere) that causes deviations from the routes.

4. And as a consequence, there is a lack of a clear schedule, which in turn does not allow planning the traffic.

In terms of financial flows, the current transport system is rightfully described as non-transparent. Despite the fact that under the current model, the city authorities do not have any participation or control over the financial turnover of the system, however, they are primarily responsible for the lack of transparency and accountability. In this regard, some of the existing problems are listed below:

1. the problem of generating income in the context of the relationship between the driver and the service provider, when the driver has to "to fulfil the plan", with all its consequences (drivers working without shifts),
2. uncontrolled financial flows, shadow cash turnover, as a consequence – hidden taxes,
3. cash collection system with the driver's participation that causes security and service quality problems,
4. lack of data on passenger traffic, "petrified" route network, which does not respond to demand and continues to be inconsistent with reality.

The current transport system also has a number of obvious technical shortcomings (drivers' service quality, sanitary condition, worn-out and inaccessible fleet, etc.), which are of great importance for the population. However, it is necessary to mention the limitations that caused these shortcomings: the problem concerns the management model and the legal framework.

The current model and legal framework do not enable development for new investments and clear management. The existing model is built based on a tender for separate route lanes management, where the main component is the fare offered by the participant.

As a result, unequal conditions arise, such as good and bad lanes; the investor's return on investment is not guaranteed; the established standards of service are, to put it mildly, out of date. According to the RA Government Decree No. 762 of August 16, 2001, the fare is formed based on the offer of the winning organization. According to the said Decree, different tariffs may be applicable on different routes, but in fact, the tariff offer is actually of a formal character, as the community restrains the increase of tariffs, which leads to the closure of existing routes due to their unprofitability (Figure 7).

Among the above-mentioned problems, the current model lacks effective and modern quality control mechanisms, and in case of poor quality service, there are no restraining or quality-promoting measures. The only effective way is to terminate the contract, which, however, also has its risks.

It is also very important to take into account the interrelated urban problems that arise from a non-viable transport system, such as continuous growth in the number of personal cars, overload of central streets, aggravation of parking problems and, as a result, emissions growth and air pollution.

IV. PROBLEM SOLVING STEPS AND PROSPECTS

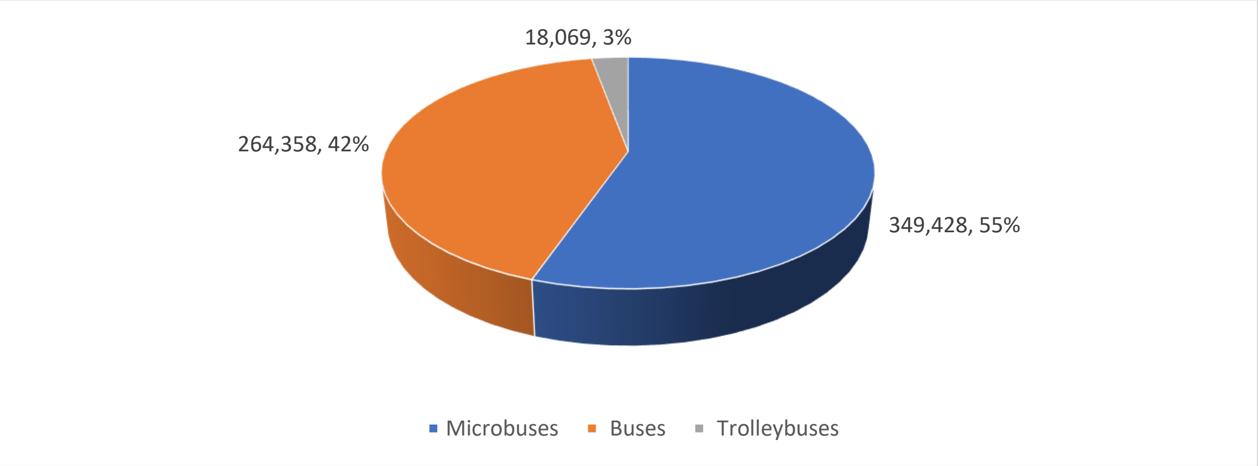
In order to start designing the new route network, first of all, it was necessary to understand the passenger traffic serviced by public transport in Yerevan. In 2013, "Breavis" Institute for Political and Social Consulting LLC was hired to study the passenger traffic in Yerevan. The said company conducted a large-scale study of passenger traffic in the following format:

1. The number of passengers getting on and off each type of vehicle was calculated by the company employee,
2. Surveys in households were carried out.

The above-mentioned measures implementation allowed to form a clear picture of the daily passenger traffic, as well as of the movement of passenger traffic: among macro and micro zones of the city.

In 2017, Yerevan Municipality demanded to check the data obtained in 2013; as a result, a final report on the daily passenger traffic of public transport in Yerevan was drawn up. Briefly, it can be presented as follows:

Figure 12. Stable passenger traffic in Yerevan



In 2016, Yerevan Municipality signed a contract with “WYG” company, the winner of the tender for the design of a new route network in Yerevan, which was announced with the funding of the Asian Development Bank. Under the contract, “WYG” was required to develop a cost-effective new route network that would meet the following requirements:

- Designing the network in accordance with international standards, without linking it to the current network,
- Providing full service coverage of the city, taking into account the streets capacity, surveys in households and studies of the passenger traffic in Yerevan,
- Minimizing the number of overlapping lines, reducing the required fleet, ensuring maximum cost efficiency by designing a network of integrated and complementary routes based on the principle of changes,
- Excluding the operation of minibuses, taking into account the public demand and efficiency,

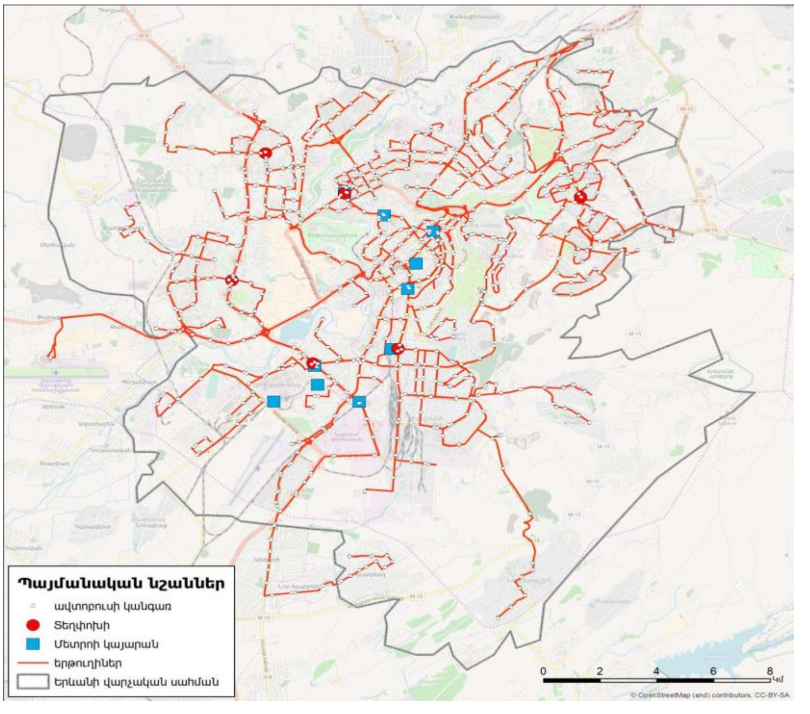
- Considering the number of stops, their location and capacity in order to prohibit stops in unauthorized places,
- Considering the possibility of allocating a separate roadway for public transport in order to increase the speed of service, as well as to emphasize the priority of public transportation,
- Designing the network for the administrative area of Yerevan, with some exceptions, as servicing of the network outside Yerevan leads to inefficient costs due to passenger traffic, as well as in some cases the road network does not correspond to the planned transport service.

Under the contract, “WYG” was to submit 10 reports to be approved by Yerevan Municipality. In 2019, the reports submitted by “WYG” were officially approved by Yerevan Municipality.

The new route network consists of 42 bus routes, 11 of which are main routes, 30 are auxiliary or feeder roads, and 1 route is the road to the airport. Five existing trolleybus routes were integrated into the network as well.

The main routes are planned to be serviced by high-capacity buses (18 m long with 150 passengers capacity), and feeder lines - by high and medium-capacity buses (8-12 m long with 58-100 passengers capacity). The calculation and verification of the necessary transport capacity by route lines was carried out using the appropriate software model. The only stable transport component required for the new route network is the dimensions that were calculated as a result of calculating the passenger traffic on this route, and the mode of transport can be modified depending on the available financial resources. The new route network can be serviced either by diesel or compressed natural gas buses, or by electric buses.

Figure 13. New route network of Yerevan



The figure demonstrates the preliminary appearance of the proposed transport network. It shows the maximum possible complete coverage, the overlapping lines have been minimized, the coverage of stops has been designed in a way so that the passenger would arrive at the bus stop in case of a 5 minute walk or 400 m on average, (or a 10 minute walk maximum).

The new network defines the description of each route, the required mode and quantity of transport, the route length, the frequency of departures by working and non-working days and hours, and operating speed. By increasing the capacity of vehicles servicing the new route network, the calculation is based on an average load factor of up to 70%, ensuring reliability and comfort:

According to the indicators of the new network, the average service frequency is 9 minutes, instead of the current irregular and arbitrary service. Moreover, an average of 6 minutes of service frequency is planned during peak hours, and during non-load hours - 8.5-15 minutes. The start and end hours are scheduled from 6: 45 to 23: 45 instead of the current 7: 00 to 23: 00, taking into account the demand of the population and the need to fully service urban life.

The new network is planned to be serviced by **845 vehicles instead of the current 1922 units**. The number of vehicles will be reduced by about 2.3 times and replaced with high-capacity fleet. By the way, this figure includes the number of backup vehicles, which is 15 percent by internationally recognized standards: i.e., the network will be serviced by 733 buses.

As a result of the network reintegration, excluding overlapping lines, the **total network length will be reduced by about 3.5 times, from today's 3,961 km to 1,134 km,** while providing the existing coverage.

The most significant reduction and savings can be seen from the data on the annual mileage of the fleet in the existing and new networks, as this forms the main expenditure component. With the current network, **the total annual mileage of the fleet is 200.7 million km, while with the new network - 58.0 million km, reduced by about 4 times**. The stated 58.0 million km. includes zero mileage of the fleet that is equal to 5% of the total mileage.

The next comparative data of the new route network refers to the number of stops and changes. The new network proposes **to increase the number of stops from 834 to about 1,200**; however, this does not mean a slowdown in traffic, as there will be a clear schedule.

The only convenience of the current route network of public transportation for citizens is probably a low indicator of changes, since a citizen can make a trip from any point in one vehicle, which, however, is accompanied by a longer travel time. However, as in all developed cities, the effectiveness of the route network can only be achieved by applying the principle of changes, which reduces the travel time. At that, if with the current network 94% of passengers travel without changes, with the new network this indicator is equal to 45%; one change - 37% and two changes - 15%.

The existing trolleybus network also forms a part of the new route network and is fully integrated into it; however, it is subject to complete retrofit. In order to operate the existing routes in accordance with the new network, 34 existing and still usable trolleybuses must be repaired and re-equipped, **67 new trolleybuses** must be purchased, and the corresponding infrastructure must be repaired. The estimated investment amount is about 43 million euros.

4. Best practice of energy saving in the transport sector

Greenhouse gas emissions from the transport system increase every year, accounting for about 29% of global CO2 emissions.[2] The high level of emissions from the transport sector is conditioned by the following factors:

- Overpopulation,
- Use of fossil fuels,
- Inefficient transport system,

[2] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

- Lack of clear environmental standards and regulations.

The main objective of urban transport is to create an opportunity to meet the demand for passenger and cargo transportation without having a negative impact upon society and the environment. This approach should be guided by the following principles:

- Implementing proper land use and planning, resulting in reduced distances (kilometers). Designing an efficient transport network;
- Implementing policies to encourage people to use vehicles with low emissions and energy saving vehicles, such as public transport and vehicles without internal combustion engines. This can be implemented through investments by improving the public transportation system, creating a secure infrastructure, and reducing initiatives to use personal vehicles with internal combustion engines (environmental charges and fuel prices);
- Implementing policies to reduce the harmful effects of vehicles with internal combustion engines. This can be achieved through policies such as improving the efficiency of vehicle fuel, consumption of low-carbon fuel through new technology, and encouraging the use of vehicles with low emissions such as electric and hybrid vehicles.

Depending on financial possibilities and priorities, different cities respond differently to climate change actions.

1. *Mitigation.* These are steps aimed at stabilizing greenhouse gases emissions that allow decision makers to improve the transportation system's efficiency: high-quality public transportation, secure walking and cycling infrastructures, energy saving vehicles to reduce emissions.
2. *Adaptation.* These are steps to make the transport system more flexible: improving the transport infrastructure, repairing roads, and building new infrastructures.

As I have already mentioned, world experience shows that urban transport is rapidly becoming a significant energy consumer. The main energy sources are non-renewable oil fuels. In this regard, it is necessary to assess the factors and strategies that affect the energy savings of public transportation.

First of all, it should be noted that the main impetus for the establishment of urban transport, as well as for its development, is the public demand for transport. Thereby, in recent years, cities have begun to think about the development of demand management strategies that will reduce the demand for transport. This logic implies the following approach: if the demand decreases, the energy consumption of public transport will also decrease. Based on the experience of different cities, as well as international experience, it should be noted:

- Urban transport is a significant energy consumer,
- Consumption increase is conditioned by urban population growth,
- An effective toolkit is needed,
- Improving the efficiency of urban transport makes it possible to reduce energy consumption.

There are three factors that affect the energy consumption of urban transport. They are **territory regularity, income level and vehicle type**.

Territory regularity and population size are both important factors. Dense housing leads to a reduction in the number and length of trips, which reduces the energy consumption by transport.

Income level in the city is the next factor for energy consumption. In high-income cities, the population tends to use personal vehicles, often also expensive vehicles with high energy consumption, while in low-income cities the situation is reversed - people cannot afford to buy personal cars, they use public transportation, bicycles, or walk.

Types of vehicles also have an impact on the city's energy consumption. This is due to the fact that cities that have poor legislative regulations and allow the use of old vehicles, which are very often in a faulty condition, lead to greater energy consumption.

As a result, taking into account the above-mentioned examples, as well as international experience, in order to improve transport demand and reduce energy consumption, it is necessary to implement the following strategies:

- **Avoiding** actions that lead to the increase in demand for transport,
- **Modifying** actions that will encourage people to use vehicles with lower energy consumption, such as public transport and vehicles without internal combustion engine,
- **Improving** the transport system in the city, thus reducing emissions, energy consumption and noise level.

Within the framework of the previously mentioned strategies below we refer to the two groups of actions to reduce the energy consumption level in urban transport.

1. Management actions:
    - Actions that will reduce trip length, decrease the distance between localities, and make cities more compact,
    - Actions that will make public transportation more attractive,
    - Actions that will improve traffic, speed, resulting in reduced energy consumption of the vehicle in a standing state,
    - Actions that require more attention to vehicle repair and maintenance.
2. Technological actions include telecommunications (reducing travel demand) and introduction of efficient alternative fuel technologies.

5. Environmental impact of transport

Environmental degradation is an important and growing problem for a number of developing cities. Transport can have a number of impacts on the environment. Among them are the following:

- Air quality degradation,
- Energy consumption,
- Noise,
- Water quality degradation,
- Greenhouse gas emissions.

There are quite a lot of problems related to environmental degradation, and they often require new legislative regulations. In order to form legislative initiatives, first of all, it is necessary to understand the causes of problems and alternative solutions for their regulation.

In view of air quality degradation, it is necessary to assess the ambient air quality by composition and amount of emissions from various sources (static and mobile).

Each of these factors is subject to different restrictions in the world. For instance, National environment agencies usually publish legislative restrictions on ambient air quality[3]: Similarly, different countries restrict the permissible volumes of emissions (factories, cars).

The main components of air pollution are as follows:

- **Particulate matters**: very minute particulate matters (PM10 PM5 PM2.5), consisting of various substances that are extremely hazardous, as they can penetrate into people's respiratory system of, causing various health problems. Basically, these particles consist of soot (black smoke), which is the result of incomplete combustion of solid coal bodies. Diesel vehicles with internal combustion engines are the main source of such particulate matters in the urban environment. At the same time, there are other types of particles that are also harmful. Hydrocarbons can form another important proportion of mass particles. For instance, an improper ratio of oil and fuel in engines can lead to this type of pollution (white smoke). The harmfulness of these particles is mainly estimated by their size. The smaller the particles, the more harm they can cause. By the end of the last century, the main emission standards were limited to 10 microns or less (PM 10), which gradually decreased to 2.5 microns or less (PM 2.5).
- **Toxic and carcinogenic gases:** They are mainly related to the following gases: carbon monoxide (CO), sulfur oxide (SO), sulfur dioxide (SO2), nitrogen dioxide (NO2), and many types of hydrocarbons.
- **Ground-level ozone** (smoke) O3, which is the result of a combined chemical reaction produced by volatile organic compounds (VOCs), nitric oxide (NOx), and sunlight.

Ambient air quality in a number of developing countries is controlled by guidelines, such as the air quality guidelines offered by the World Health Organization. The following emissions are the main subject of regulation as a consequence of transport pollution:

- NOx,
- CO,
- VOCs,
- PM 10,
- PM 2.5.

Actions to regulate the ambient air quality should be carried out following the principle of "avoiding, modifying and improving". It is necessary to Avoid and Modify the total mileage of passenger and cargo vehicles, as well as Avoid and Modify the amount of emissions per vehicle kilometers traveled (VKT).

[3] http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf)

In some countries, urban transport is associated with ambient air composition of one third PM10 and much more PM2.5. Particulate matters (PM) are associated with respiratory and cardiovascular diseases that are carcinogenic. They also cause an increase in the levels of asthma among the most vulnerable groups - children and the elderly. Unlike pollutants from compressed natural gas, the particulate matters can appear in the lung tissue, causing damage much later. For this reason, this health problem is more pronounced in the cities of developing countries, where population density is gradually increasing.

Particles emitted from vehicles cause 1.2 million deaths worldwide each year.

Strategies for reducing particles (PM) emitted from vehicles are as follows:

- Reducing the operation of vehicles with the highest emissions in densely populated areas,
- Improving vehicle technologies.

There is a number of approaches for calculating the particulate matters (PM) emitted in the city, but the main problem is to find a solution to understand their origin.

As stated above, one of the strategies for reducing particulate matters is to reduce the operation of such vehicles in densely populated areas. This can be done by prohibiting the operation of old vehicles, restricting their operation in certain places, or modifying the urban logistics, making it pointless to operate such vehicles in the areas near people. In some countries, this problem is solved by prohibiting the movement of large vehicles in the city or encouraging their replacement with smaller vehicles.

The second approach is to improve transport through technological solutions. This method is more expensive and leads to an increase in operating costs. Such costs, in turn, lead to an increase in the cost price, which falls on the final consumer.

There are two types of technology for reducing the particles emitted by large diesel vehicles:

1. Using a “smarter” engine with an upgraded fuel system and computer control module of operation. However, often it is not possible to implement such an approach in developing countries;
2. Using a more sophisticated and secure vehicle exhaust system, such as oxidation catalysts and particulate filters. This technology can be applied for a wide range of consumption, but it can only be used if there is a low level of sulfur in the existing fuel. Thus, in order to be able to apply this technology, it is necessary to ensure a low level of sulfur in the composition of the fuel sold.

In addition to the technological solutions mentioned above, it is also recommended to replace diesel engines with compressed natural gas engines. This approach is proposed for vehicles of wide application: buses, trucks, and can also be considered for the development of trolleybus economy or the use of electric vehicles.

Compressed natural gas (CNG) vehicles are equipped with spark-ignition technology, like gasoline engines, but are more able to provide the required power and the ability to rotate during heavy vehicle operation. They emit less NOx or smoke into the atmosphere than diesel engines.

However, the said CNG vehicles (buses) are more expensive than the diesel ones. The price difference is 20-30%. For instance, in the case of buses, it is due to the fact that in order to apply the technology of compressed natural gas in low-floor buses, a structural change of the bus must be made to install such systems. Compressed natural gas vehicles are less energy efficient because the spark-ignition system has a lower coefficient of compression than the vehicles equipped with compression-ignition engine system. Moreover, compressed natural gas vehicles must be equipped with fuel tanks, which further increase the weight of the vehicle that also affects the fuel efficiency.

The use of compressed natural gas vehicles is mainly conditioned by a number of economic calculations. Since the initial purchase price of such vehicles is higher than that of diesel ones, the fuel is usually cheaper. Maintenance and operating costs also vary. Thus, the use of such transport cannot be conditioned only by the regulation of environmental issues: it must also be based on economic calculations.

As I have already noted, noise also has a big impact on the environment. Noise reduction is regulated by EU Directive 2002/49/EC. In a number of developing countries, reducing noise pollution is considered a luxury, as they find that there are more important and higher priority environmental issues.

Traffic is the main source of noise: the faster the traffic, the higher the noise level. This means that if traffic improves in overpopulated areas, the noise level will also increase. However, this connection is not directly proportional, since large vehicles make more noise than small ones, and by prohibiting large vehicles from entering populated areas, the noise level will decrease; in addition, specific measures must be applied for specific cases.

The impact of transport on water quality is less than the impact of transport on air quality, but the effect on water quality cannot be considered insignificant. Emissions from the transport system affect the soil and road surface in different ways, in particular due to improper repairs of vehicles and poor management of emissions. Inadequate quality of repairs can lead to leaks in transport lubricating oils, increased emissions, losses of cargo, tire damage, and road surface damage. At the same time, the increase in transport infrastructure leads to an increase in permeable surfaces, through which rainwater can pollute filtration and drainage systems with sand and soil. As a consequence of all this, the released oil and other particles from the road surface can enter the mentioned systems. Such problems are mainly caused by poorly planned urban development processes.

Based on the research conducted in different countries, it has become clear that the transport system and its structure have an impact on physical activity and, consequently, on the health of the population of a given country. This is conditioned by the following logic: an hour driving contributes to a weight gain equal to 6% (this is measured by the Body Mass Index). At the same time, every kilometer of walking gives a 4.8% chance of not gaining weight. Research also shows that driving is the main source of a physically inactive lifestyle. Here there is a risk that the wrong design of the transport system in the cities of developing countries and the promotion of personal cars use will lead to a decrease in physical activity of the city's population.

V. CALCULATION OF EMISSIONS FROM THE TRANSPORT SECTOR

All the above components have their impact on the environment, thus the need to measure this impact naturally arises. The environmental impact of transport can be measured using the following two methods:

1. Measuring the impact comparing it with appropriate existing standards and indicators, if any
2. Measuring the impact comparing it with changes resulting from appropriate actions and interventions.

To measure the benefits resulting from interventions in the transport sector, it is common to use the existing volume of air and greenhouse gas emissions. However, this logic raises the following problem: in order to measure accurately the comparisons of previous and current air quality and greenhouse gas emissions, it is necessary to compare the previous indicators with such current indicators that would occur if quality interventions were not implemented.

6. International standards and methodology of emissions calculation

Among the greenhouse gases controlled by the UN Framework Convention on Climate Change, those related to the transport sector include: carbon dioxide (CO_2) and sulfur dioxide (SO_2); methane (CH_4) from gas vehicles, as well as Black Carbon (BC), which is a fraction of particulate matters formed mainly by diesel vehicles. Black Carbon (BC) of greenhouse gases consists of $PM_{2.5}$ and GWP100 emission particles.

In compliance with 2006 IPCC Guideline, TTW (tank to wheel) greenhouse gas emissions from vehicles are calculated based on the amount of fossil fuel consumed, in particular the Net Calorific Value (NCV) of fuel and CO_2 emissions (EF CO_2). Greenhouse gas emissions directly include also methane emissions from gas engines. The outflow of unburned methane CH_4 has a significant impact on the Global Warming Potential. Methane emissions are generated in the vehicle trunk and in the exhaust system through outflow of gas pumps.

There are also well-to-tank (WTT) emissions. Indirectly, well-to-tank (WTT) emissions are the emissions related to fuel consumption that include greenhouse gases from production, processing and delivery of fossil fuels. The latter envisages a factor by type of fossil fuel. With regard to electric vehicles, emissions of this type are determined for the production of electrical energy using fossil fuels. The carbon emission factor is calculated based on the actual energy generated (total internal generation minus energy losses) and total greenhouse gas emissions for electrical energy generation.

Greenhouse gases are also generated from the production of vehicles or their components, in particular from the production of electric vehicle batteries. For battery production, the amount of greenhouse gas emissions is calculated from 56 to 494kgCO_2e/kWh, while the average specified factor is 110kgCO_2e/kWh. With regard to greenhouse gas emissions from the production of electric vehicles, it should also be taken into account that the battery, after its useful life, can be used in other stationary systems. Yet, electric vehicles are considered more durable, since they cause less vibration and possess other structural details. Emissions generated from the production of an electric vehicle battery are compensated for within 4-13 months compared to a fossil fuel vehicle, depending on the vehicle type.

The entire process of greenhouse gas emissions from the transport sector consists of WWT (well to tank) + TTW (tank to wheel) = WTW (well to wheel). This implies emissions from fuel production and delivery plus emissions from fuel consumed by transport. Since vehicle fuel is fully imported into the Republic of Armenia, the TTW (tank to wheel) factor must be applied to calculate greenhouse gas emissions.

The previously mentioned guideline details the amount of greenhouse gas emissions from combustion of various fuels by transport type.

Table 4. Greenhouse gas emission factor according to IPCC, 2006

Indicator	Value	Unit	Source
Diesel caloric value NCV	43	MJ/kg	IPCC, 2006, table 1.2
Diesel CO2 emission factor	74.1	gCO2/MJ	IPCC, 2006, table 1.4
Diesel CH4 emission factor	0.0039	gCH4/MJ	IPCC, 2006, table 3.2.2
Diesel SO2 emission factor	0.0039	gSO2/MJ	IPCC, 2006, table 3.2.2
Diesel density	0.844	kg/l	IEA, 2005
CNG caloric value NCV	48	MJ/kg	IPCC, 2006, table 1.2
CNG CO2 emission factor	56.1	gCO2/MJ	IPCC, 2006, table 1.4
CNG CH4 emission factor	0.092	gCH4/MJ	IPCC, 2006, table 3.2.2
CNG SO2 emission factor	0.003	gSO2/MJ	IPCC, 2006, table 3.2.2
CNG density	0.714	kg/m3	IGU, 2012
Gasoline caloric value NCV	44.3	MJ/kg	IPCC, 2006, table 1.2
Gasoline CO2 emission factor	69.3	gCO2/MJ	IPCC, 2006, table 1.4
Gasoline CH4 emission factor	0.033	gCH4/MJ	IPCC, 2006, table 3.2.2
Gasoline SO2 emission factor	0.0032	gSO2/MJ	IPCC, 2006, table 3.2.2
Gasoline density	0.741	kg/l	IEA, 2005
LPG caloric value NVC	47.3	MJ/kg	IPCC, 2006, table 1.2
LPG CO2 emission factor	63.1	gCO2/MJ	IPCC, 2006, table 1.4
LPG CH4 emission factor	0.062	gCH4/MJ	IPCC, 2006, table 3.2.2
LPG SO2 emission factor	0.0002	gSO2/MJ	IPCC, 2006, table 3.2.2
LPG density	0.525	kg/m3	EMEP, 2019

7. Emissions from the transport of Yerevan

As a result of studying the state register of the RA Traffic Police, it became clear that the average age of the vehicles registered in the Republic of Armenia, as well as in Yerevan is more than 10 years. This indicator has a negative impact on the level of emissions from the vehicles in use, since due to the lack of appropriate legislative regulations in Armenia, vehicles do not pass proper technical inspection: as a result, some vehicles are in poor condition and do not meet the technical inspection requirements. Moreover, depending on the quality of the fuel, technical problems arise in the vehicle exhaust system, related to the catalyst system, which, due to poor fuel quality, clogs up and causes malfunction of the vehicle engine. The stated problem is solved by the vehicle owners through removing the catalyst assembly from the exhaust system, which leads to a violation of the environmental norm developed by the vehicle manufacturer, as by means of the corresponding spark plug and as a result of a power spark, double combustion of incompletely burned gases occurs.

The removal of catalysts is also advantaged by the fact that the substances removed from catalysts are purchased by different businesses at a high cost, as they contain various precious metals. Here is an example: if you sell a catalyst of an Opel Astra (production year 1998-2002) to various businesses, you can get an amount of about 70,000-110,000 AMD. This makes it possible for businesses engaged in vehicle sales to sell the catalyst of a newly imported vehicle, thus reducing the cost price of the vehicle and sell it, being more flexible on the vehicle market.

Taking into account the facts above, it can be stated that a significant part of the total number of vehicles registered in Yerevan do not possess exhaust system catalysts: as a result, the emissions from these vehicles do not comply with factory specified standards.

For accurate calculation of vehicle emissions in Yerevan, it is also important to take into account the types of the vehicle engines and the types of the fuel used. The data in the tables below show that the weight of compressed natural gas in the total volume of fuel and energy carriers is about 60%.

The following data published by Statistical Committee of the RA served as a basis for calculating vehicle emissions.

Table 5. Volume of fuel consumed by the RA transport sector, 2017

Fuel type	CNG	Gasoline	Diesel	LPG
Fuel consumption, kg	340,935,000	142,213,300	94,473,800	4,761,900
Share in total fuel, %	59	24	16	1
Share in oil and petroleum products, %		58.9	39.1	2.0

Table 6. Energy balances of the RA transport sector, 2018

Year	CNG	Gasoline	Diesel	LPG
2015 (ktoe)	401	136.1	97	5.9
2016 (ktoe)	386.5	146.7	74.8	3.4
2017 (ktoe)	395.1	148.4	96.1	5.2
2018 (ktoe)	454.7	146.6	87.9	14.4
2016 Annual growth , %	-3.6	7.8	-22.9	-42.4
2017 Annual growth , %	2.2	1.2	28.5	52.9
2018 Annual growth , %	15.1	-1.2	-8.5	176.9

Table 7. Energy balances of the RA by energy carriers, 2018

Fuel type	CNG	Gasoline	Diesel	LPG
Energy carrier (ktoe)	454.7	146.6	87.9	14.4
Share in total fuel, %	65	21	12	2
Share in oil and petroleum products, %		58.9	35.3	5.8

As well as the forecasting indicator of 2020 energy carriers available in the development strategy report of the Armenian energy system until 2036 prepared by the Ministry of Territorial Administration and Infrastructure of the Republic of Armenia:

Table 8. Forecast of energy consumption by the RA transport in 2020

Fuel type	Measurement unit (PJ)
CNG	20
Oil and petroleum products	13.4
Total	33.4

Taking into account the available information stated above, we will use 3 calculation methods to calculate the volume of emissions from the transport sector in Yerevan:

1. Calculation of emissions based on the volume of fuel consumed by the RA in 2017, according to table 5,
2. Calculation of emissions based on the energy balances of the RA in 2018, according to table 7,
3. Calculation of emissions based on forecasting indicators of energy consumption by the RA, according to table 8.

1. Method

Based on the volumes of fuel consumed, as contained in table 5, and the emissions calculation methodology[4], the volumes of fuel consumed must be converted to energy consumed, which will be presented as follows:

Table 9. Energy consumed by the RA transport sector, 2017

Energy consumed by the RA transport sector in 2017 by volume of fuel consumed				
Fuel type	**CNG**	**Gasoline**	**Diesel**	**LPG**
Energy consumption (MJ)	16,364,880,000	6,300,049,190	4,062,373,400	225,237,870
Share in total energy, %	61	23	15	1

Calculation of the gases emission volumes[5] by energy consumed:

Table 10. Emissions from the RA transport, 2017

Calculation of emissions from the RA transport sector, 2017			
Fuel type	**gCH4**	**gSO2**	**gCO2**
CNG	1,505,568,960	49,094,640	918,069,768,000
Gasoline	207,901,623	20,160,157	436,593,408,867
Diesel	15,843,256	15,843,256	301,021,868,940
LPG	13,964,748	45,048	14,212,509,597
Total	1,743,278,587	85,143,101	1,669,897,555,404
Total (tons)	1,743.3	85.1	1,669,897.6

In the upshot, it turns out that as a result of the volumes of fuel consumed in the Republic of Armenia in 2017, greenhouse gas emissions were generated in the amount indicated in table 10.

[4] Table 4. NVC indicator

[5] Table 4. Emission factor

Because the number of vehicles registered in Yerevan is equal to 38% of the total number of vehicles, and relying on the annual growth rate[6] of energy carriers shown in table 6, it is possible to calculate the volume of emissions from the transport sector of Yerevan for 2020.

Table 11. Emissions from the transport of Yerevan, 2020

Calculation of emissions from the transport sector in 2020 as per 2017 indicators			
Greenhouse gas	**CH4**	**SO2**	**CO2**
Emissions in the RA in 2017 (tons)	1,743	85	1,669,898
Share of vehicles in Yerevan, (%)	38	38	38
Emissions in Yerevan in 2017 (tons)	662	32	634,561
Annual growth of energy carriers, (4%)	12	12	12
Emissions in Yerevan in 2020 (tons)	742	36	710,708

2. Method

Based on the 2018 energy balances presented in table 7, it is possible to obtain the data on energy consumption by the transport sector in 2018. The calculation is based on the assumption that 1 ktoe is equal to 41868 megajoules of energy (1ktoe=41868MJ).

Table 12. Energy consumed by the RA transport sector, 2018

Energy consumed by the RA transport sector in 2018 by energy carriers				
Fuel type	**CNG**	**Gasoline**	**Diesel**	**LPG**
Energy consumption (MJ)	19,037,379,600	6,137,848,800	3,680,197,200	602,899,200
Share in total energy, %	65	21	12	2

Calculation of the gases emission volumes[7] by energy consumed:

Table 13. Emissions from the RA transport, 2018

Calculation of emissions from the RA transport sector, 2018			
Fuel type	**gCH4**	**gSO2**	**gCO2**
CNG	1,751,438,923	57,112,139	1,067,996,995,560
Gasoline	202,549,010	19,641,116	425,352,921,840
Diesel	14,352,769	14,352,769	272,702,612,520
LPG	37,379,750	120,580	38,042,939,520
Total	2,005,720,453	91,226,604	1,804,095,469,440
Total (tons)	2,005.7	91.2	1,804,095.5

In the upshot, it turns out that as a result of the volumes of fuel consumed in the Republic of Armenia in 2018, greenhouse gas emissions were generated in the amount indicated in table 13. Taking into account the fact that the number of vehicles registered in Yerevan is equal to 38% of the total number of vehicles, as well as the annual growth rate of energy carriers shown in table 6, it is possible to calculate the volume of emissions from the transport sector of Yerevan for 2020.

[6] Annual growth rate is estimated at 4%

[7] Table 4. Emission factor

Table 14. Emissions from the transport of Yerevan, 2020

Calculation of emissions from the transport sector in 2020 as per 2018 indicators			
Greenhouse gas	**CH4**	**SO2**	**CO2**
Emissions in the RA in 2018 (tons)	2,006	91	1,804,095
Share of vehicles in Yerevan (%)	38	38	38
Emissions in Yerevan in 2017 (tons)	762	35	685,556
Annual growth of energy carriers, (4%)	8	8	8
Emissions in Yerevan in 2020 (tons)	823	37	740,401

3. Method

Based on the forecasting indicators of energy consumption in 2020 presented in table 8, as well as the oil and petroleum products share indicators shown in table 5, the forecast volume of fuel consumption by fuel type will be as follows:

Table 15. Forecast of energy consumption in the RA in 2020

Forecast of energy consumption by the RA transport in 2020	
Fuel type	**Measurement unit (MJ)**
CNG	20,000,000,000
Gasoline	7,892,591,065
Diesel	5,243,131,759
LPG	264,277,177

Calculation of the gases emission volumes[8] based on the indicators of energy consumption in 2020, as presented in table 5:

Table 16. Emissions from the RA transport, 2020

Calculation of emissions from the RA transport sector, 2020			
Fuel type	**gCH4**	**gSO2**	**gCO2**
CNG	78,000,000	60,000,000	1,122,000,000,000
Gasoline	260,455,505	25,256,291	546,956,560,789
Diesel	20,448,214	20,448,214	388,516,063,318
LPG	16,385,185	52,855	16,675,889,840
Total	375,288,904	105,757,361	2,074,148,513,947
Total (tons)	375.3	105.8	2,074,148.5

In the upshot, it turns out that as a result of the forecast energy consumption in the Republic of Armenia in 2020, greenhouse gas emissions will be generated in the amount indicated in Table 16. Because the number of vehicles registered in Yerevan is equal to 38% of the total number of vehicles, and relying on the annual growth rate of energy carriers shown in table 6, it is possible to calculate the volume of emissions from the transport sector of Yerevan for 2020.

[8] Table 4. Emission factor

Table 17. Emissions from the transport of Yerevan, 2020

Calculation of emissions from the transport sector in 2020 as per 2020 forecasting indicators			
Greenhouse gas	**CH4**	**SO2**	**CO2**
Emissions in the RA in 2020 (tons)	375	106	2,074,149
Share of vehicles in Yerevan (%)	38	38	38
Emissions in Yerevan in 2020 (tons)	143	40	788,176

Based on the data obtained from all the calculation methods, an analysis has been performed and the deviation scope of the obtained results has been indicated, which is shown in Table 18:

Table 18. Comparison of methods for calculation of emissions from the transport of Yerevan

Greenhouse gas	CH4	SO2	CO2	Deviation percent
Calculation of emissions from the transport sector in 2020 as per 2017 indicators	**742**	**36**	**710,708**	
Calculation of emissions from the transport sector in 2020 as per 2018 indicators	**823**	**37**	**740,401**	**4.2**
Calculation of emissions from the transport sector in 2020 as per 2020 forecasting indicators	**143**	**40**	**788,176**	**6.4**

VI. EMISSIONS REDUCTION POLICIES

8. Medium-term policy of emissions reduction

To reduce emissions from the transport sector of Yerevan, both the city authorities and the Government of Armenia should implement a number of measures. In matters of transport regulation, the issue of regulating the public transportation in Yerevan is a priority, since it is impossible to solve other problems without solving the main one. Studies of international experience have shown that the main priority of regulating the transport sector is a proper transport planning.

In Yerevan, as a medium-term policy for 2020-2030, it is necessary to implement the process of introducing a new route network in the city, which, as noted, should include the following reform steps:

1. Upgrading the vehicle fleet with new buses,
2. Eliminating overlapping routes in accordance with the new route network,
3. Compressed natural gas (CNG) vehicles,
4. Reducing the total length of the route network as a result of proper planning,
5. Reducing the total mileage of vehicles servicing the route network,
6. Replacing the stops,
7. Creating accessible and comfortable public transportation,
8. Modifying the traffic organization,
9. Using a separate roadway zone for public transport vehicles in the streets of Yerevan,
10. Introduction of a unified ticket system.

These actions will lead to great economic benefits for the city authorities, as well as they will solve the environmental issue by reducing the amount of emissions. These reforms imply large capital financial expenses, as a result of which the new route network will have relatively low operating (operation and maintenance) costs compared to the current route network.

If the new route network of Yerevan is introduced, taking into account the fact that the number of required vehicles significantly decreases and the annual mileage of vehicles is reduced by about 4 times, as a result of the calculation[9], we will have a significant reduction of exhaust gas emissions, as presented below.

Table 19. Emissions from the current public transportation route network

Fuel type	gCH4	gSO2	gCO2	Annual vehicle mileage (km)	Fuel consumption (g /km), source: EMEP guidebook 2019
CNG	402,983,036	13,140,751.17	245,732,046,789	177,194,595.0	515
Diesel	730,153	730,153	13,872,909,204	14,464,865.0	301
Total	403,713,189	13,870,904	259,604,955,993	191,659,460.0	

Table 20. Emissions from the new public transportation route network

Fuel type	gCH4	gSO2	gCO2	Annual vehicle mileage (km)	Fuel consumption (g /km), source: EMEP guidebook 2019
CNG	88,460,853	285,357.59	90,030,319,449	58,572,136	515
Total	88,460,853	285,358	90,030,319,449	58,572,136	

Table 21. Comparison of public transportation route networks

Reduction of emissions as a result of the new route network introduction			
	CH4 (tons)	**SO2 (tons)**	**CO2 (tons)**
New route network	88.5	0.3	90,030.3
Current route network	403.7	13.9	259,605.0
Difference	(315)	(14)	(169,575)

It is planned to keep the five existing trolleybus routes in the new route network, and within the framework of the reform, it is being discussed to preserve the trolleybus route network through retrofits or completely convert it to electric buses. In both cases, greenhouse gas emissions from the operating fleet will be equal to zero. In 2017, the European Bank for Reconstruction and Development conducted a study of the trolleybus network in Yerevan and estimated about 43 million euros for its retrofits. The option of replacing the existing five trolleybus routes with electric buses will cost almost the same amount of money.

Modifications of the road traffic should also be implemented in the processes of the previously mentioned reforms. The most important of them is the allocation of separate roadways for public transport vehicles in the streets of Yerevan. The main streets of Yerevan have an average of 3 lanes

[9] Table 4. NVC indicator and Emission factor

on each side. It is necessary that the first traffic lane in each direction be allocated to public transport vehicles. This approach will have a direct impact on the transport of Yerevan, in particular:

- Public transport will be serviced according to clear schedules,
- The average speed of public transportation will increase,
- The service quality of public transportation will be more secure and convenient,
- Other modes of transport in Yerevan will have to drive on common use lanes,
- The number of vehicles on common use lanes will increase,
- Using a personal car will become less attractive.

As a necessary component of the public transportation reform, introduction of the traffic management systems should be noted as well:

- Smart and remote controlled traffic lights,
- Passenger traffic calculation tools,
- Smart transport management system,
- Construction of bypass roads and infrastructures.

Reforms of Yerevan public transportation will allow the city to have a route network that meets international standards, and as a result of its proper operation the city authorities will be able to apply other restrictions, making people give up personal cars. For example:

- Increasing fees for paid parking,
- Increasing vehicle property tax.

In the medium-term policy concept, it is also necessary to implement a number of legal regulations that will indirectly affect the reduction of emissions from the transport sector of Yerevan. These legal regulations must be established by both the city authorities and the government of the Republic of Armenia:

- Applying stricter standards for certification of taxi services and individual drivers and increasing the certification fee,
- Prohibiting the operation of vehicles with removed or faulty catalysts and establishing administrative liability,
- In accordance with the Comprehensive and Enhanced Partnership Agreement, setting a limit on average daily permissible amount of pollutants and making a list of substances, monitoring them and establishing administrative liability,
- Accurate implementation of vehicles technical inspection,
- Increasing nature protection payments provided for vehicles,
- Encouraging the use of electric vehicles, establishing incentives for their use, and creating infrastructure to ensure their recharging.

The medium-term policy of the aforementioned reforms will have a direct impact on the level of emissions from the transport of Yerevan, such as:

- New infrastructure and roads will force vehicles to bypass Yerevan,
- Reducing 1/3 of the roadway will result in fewer vehicles,
- The new public transportation route network will service more passengers,

- Increases in parking fees and vehicle property tax will force people to give up personal vehicles,
- Transport management systems will increase the average speed of transport,
- Stricter legal regulations will force people to give up personal vehicles.

Preliminary analyses clearly show that the only direction aimed at reducing the amount of emissions is the authorities' policy to restrain transport and as a result of its implementation the emissions indicator will be significantly lower.

9. Long-term policy of emissions reduction

The long-term policy of emissions reduction from the transport sector in Yerevan involves the development of concepts for 2020-2050 and measures to implement these concepts. It must continue to undertake the planned steps and, over time, apply newer technologies that will contribute to emissions reduction. The four main directions should be mentioned as a long-term policy:

1. Proper management of the transport system
2. Reducing the use of vehicles for personal use
3. Stricter legal regulations aimed at emissions reduction
4. Widespread use of electric vehicles

The transport system management consists of ongoing measures conditioned by the city development. The transport sector must have a unique impact on the sustainable development of the city and must be an integral part of it. Yerevan is a constantly evolving ecosystem, and road infrastructure is a limited resource, so for sustainable development of the city, it is necessary to consider the possibilities of using limited resources as well. For example, to build a new multi-apartment building, it is necessary to calculate the capacity of the roads in the area to recommend the maximal number of storeys for the buildings to be constructed. Nowadays, this function is not performed.

The transport system should be managed through the introduction of electronic methods, since traffic is also changing in parallel with the development of the city. Therefore, it is important to have accurate information. Such systems involve devices for vehicles calculation installed on roads, based on the data of which analytical analysis is carried out to make changes on the limited routes for traffic flow management and automatic change of the modes of smart traffic lights. The use of the said systems leads to an increase in traffic speed, which directly affects the service life of vehicles, as well as the level of emissions.

Reduction of vehicles for personal use is implemented as a consequence of a better alternative offer. With regard to Yerevan, it can be comfortable and secure public transporationt, which will move faster on the roads allocated for it, and in case of purchasing new fleet and replacing the old one within the stated timeframe, it will become the safest and the most secure. As a process of giving up personal vehicles, it is also necessary to introduce a culture of alternative transport (bicycles, electric mopeds, etc.) into the urban transport network, as well as to continue to apply stricter regulations related to nature protection payments for vehicles, parking fees and the amount of property tax.

In terms of emissions reduction, clear legal regulations should be created, which should contain standards for permissible volumes of emissions and types of substances emitted. These standards should be kept under strict control of the state bodies, in case of violation of which administrative fines and penalties should be established. Special control over the process of technical inspection of vehicles must be carried out. It should not be formal just to collect money, but thorough technical inspection must be conducted and the operation of faulty vehicles must be prohibited, since old and faulty vehicles lead to even more environmental pollution.

In order to increase the number of electric vehicles, the state bodies must implement a developed long-term policy. This policy should include legislative regulations on the provision of incentives. The mentioned regulations should refer to the exemption from customs duties and taxes on the import of electric vehicles, the provision of privileges in respect of operating fees and duties (property tax, parking fee, etc.). Infrastructure should be created to encourage the operation of electric vehicles and to recharge the batteries of these vehicles. These infrastructures include fast and slow charging stations that can be located in busy streets of Yerevan, as well as on the outskirts, which do not require large financial investments.

The primary component of Yerevan municipality's policy in this area should be the complete conversion of public transport fleet into electric buses. In order to implement it, it is necessary to calculate accurately the routes of the route network in terms of the total mileage and passenger traffic of this route. Based on these calculations, it will be possible to obtain data on the type of electric buses needed to service the given route, as the cost of electric buses is currently quite high, due to the capacity and power of their batteries. The mileage indicator of an electric bus with a single charge can be regulated on two principles: by installing a large battery or by equipping the given route with fast charging stations. The use of a large battery increases the initial cost of purchasing an electric bus, while the installation of fast charging stations allows charging all the vehicles on the route, thus reducing the initial cost of the bus and maintaining the set mileage indicator. As a result of the stated calculations, it will be possible to convert public transport into electric buses with the minimum required means and in this case the volume of emissions from public transportation system will be equal to zero. Naturally, such a reform requires huge capital expenditures, but within the framework of long-term policy, it will be possible to apply the world experience, which shows that a number of donor organizations provide huge grants for the use of electric buses. Moreover, every year, in parallel with the development of technology, the prices for batteries fall, which leads to lower costs for electric vehicles.

In the transport sector, such an approach is inevitable to achieve the desired result, as electric vehicles do not lead to emissions reduction, but equate them to zero. Therefore, any action to implement the policy will result in reduction of the same emission ratio.

10. Financial component of emissions reduction

The measures to reduce emissions in the transport sector, both in the medium and long term, require financial support from the state or city authorities. It should be a continuous process for the implementation of the measures planned for the given period.

Investments should be made also in Yerevan in order to implement this policy. The main component of the proposed medium-term policy is the process of introducing a new public transportation route network. To present the required investments, we will consider the basic data on the new route network:

Table 22.Data on the new route network of Yerevan

Fleet type	Number of vehicles required in traffic	Total number of vehicles required (including backup)	Total annual mileage, km	Total annual mileage (including zero milieage), km
Medium bus	488	562	31,946,997	33,544,346
Large bus	29	34	1,962,928	2,061,074
Hybrid bus	216	249	15,672,236	16,455,848
Trolleybus / Electric bus	87	101	6,200,826	6,510,868
Total	820	946	55,782,987	58,572,136

As I have already noted, the new route network should be serviced exclusively by compressed natural gas vehicles. The financial resources are required to purchase the specified number of fleet, based on average prices on the international market, are shown in Table 23.

Table 23. Cost of the fleet for the new route network of Yerevan

Fleet type	Total number of vehicles required (including backup)	Cost AMD	Amount AMD
Medium bus	562	23,474,000	13,192,388,000
Large bus	34	70,080,000	2,382,720,000
Hybrid bus	249	97,820,000	24,357,180,000
Trolleybus / Electric bus	101	180,000,000	18,180,000,000
Total	946		58,112,288,000

Certainly, such capital expenditures cannot be an end in themselves, and these investments should ensure the payback process. Therefore, it is possible to apply two types of models to introduce the new route network:

1. Yerevan will purchase the fleet and infrastructure for the new route network using its own or loanable funds
2. Yerevan will attract private investors to purchase the fleet and infrastructure for the new route network

In case of the first approach, Yerevan is both the organizer and the investor of the activities to be implemented, while in the second case, it is the superviser of the services provided.

Definitely, the amount needed to introduce the new route network is not only the cost of the fleet, but it also includes the cost of building stops, change points, building bus terminals, introducing management systems, as well as operating and maintaining the entire ecosystem. As a result of detailed calculations, taking into account the expenses of all components, as well as attracting loanable funds and selecting 12 years as the operating period of the new route network, it turns out that Yerevan needs about 25 billion AMD annually. This amount can be refunded and provide payback in case if the unified ticket system is implemented, when the fare will be charged exclusively by cashless method and transferred to the municipality account. Studies show that the daily passenger traffic of public transportation in Yerevan is 631,000 people; taking into account the existing seasonal coefficient in the transport sector and adding the passenger traffic of the metro to the specified number, it amounts to about 174,000,000 people per year. Taking into consideration that the current fare in Yerevan is 100 AMD, the amount collected annually will be equal to 17.4

billion AMD. The difference in the amount needed to introduce the new route network can be covered either by a slight fare increase or by state support.

As a consequence, the implementation of the medium-term policy aimed at emissions reduction from the transport sector will require 7.6 billion AMD.

As a result of the long-term policy, the amount required to purchase the fleet for the public transportation route network will increase, taking into account the fact that all the vehicles must be replaced with electric ones. The capital expenditures required to purchase the fleet as per this approach are shown in Table 24.

Table 24. Cost of the fleet with electric buses for the new route network of Yerevan

Fleet type	Total number of vehicles required (including backup)	Cost AMD	Amount AMD
Medium bus	562	150,000,000	84,300,000,000
Large bus	34	180,000,000	6,120,000,000
Hybrid bus	249	240,000,000	59,760,000,000
Trolleybus / Electric bus	101	180,000,000	18,180,000,000
Total	946		168,360,000,000

According to the same logic and as a result of the components application, it turns out that Yerevan Municipality needs 34 billion AMD annually, and about 17 billion AMD annually will be needed to finance the resulting deficit. In this case, it will not be possible to change the fare for public transportation to such an extent, and state support will be needed to resolve the problem. Moreover, while applying a long-term policy, the burden of the state in matters of promoting electric vehicles is increasing. In fact, the state should be prepared to waive taxes and other charges levied on vehicles of this type, as well as to provide funds to subsidize the initial price of electric vehicles.